INTERNATIONAL

Designation: D2520 − 21

Standard Test Methods for Complex Permittivity (Dielectric Constant) of Solid Electrical Insulating Materials at Microwave Frequencies and Temperatures to 1650 °C[1]

This standard is issued under the fixed designation D2520; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 These test methods cover the determination of relative (Note 1) complex permittivity (dielectric constant and dissipation factor) of nonmagnetic solid dielectric materials.

NOTE 1—The word "relative" is often omitted.

1.1.1 *Test Method A* is for specimens precisely formed to the inside dimension of a waveguide.

1.1.2 *Test Method B* is for specimens of specified geometry that occupy a very small portion of the space inside a resonant cavity.

1.1.3 *Test Method C* uses a resonant cavity with fewer restrictions on specimen size, geometry, and placement than Test Methods A and B.

1.2 Although these test methods are used over the microwave frequency spectrum from around 0.5 to 50.0 GHz, each octave increase usually requires a different generator and a smaller test waveguide or resonant cavity.

1.3 Tests at elevated temperatures are made using special high-temperature waveguide and resonant cavities.

1.4 The values stated in SI units are to be regarded as standard. The values given in parentheses after SI units are inch-pound units that are provided for information only and are not considered standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A893/A893M Test Method for Complex Dielectric Constant of Nonmetallic Magnetic Materials at Microwave Frequencies

D150 Test Methods for AC Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulation

D1711 Terminology Relating to Electrical Insulation

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this test method, refer to Terminology D1711.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *neper, n*—a division of the logarithmic scale wherein the number of nepers is equal to the natural logarithm of the scalar ratio of either two voltages or two currents.

NOTE 2—The neper is a dimensionless unit. 1 neper equals 0.8686 bel. With I_x and I_y denoting the scalar values of two currents and n being the number of nepers denoted by their scalar ratio, then:

$$n = ln_e(l_x / l_y)$$

where:

ln_e = logarithm to base e.

3.3 *Definitions of Terms Specific to Test Methods B and C:*

3.3.1 *electrical skin depth, n*—the effective depth of field penetration at high frequencies where electric currents are confined to a thin layer at the surface of conductors due to basic electromagnetic phenomena.

3.3.1.1 *Discussion*—The skin depth for copper and silver is approximately 0.002 mm at 1 GHz and decreases by a factor of 10 at 100 GHz.

[1] These test methods are under the jurisdiction of ASTM Committee D09 on Electrical and Electronic Insulating Materials and is the direct responsibility of Subcommittee D09.12 on Electrical Tests.

Current edition approved April 1, 2021. Published June 2021. Originally approved in 1966. Last previous edition approved in 2013 as D2520 – 13. DOI: 10.1520/D2520-21.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

3.3.2 *high Q cavity, n*—a rectangular cavity having a Q greater than 2000.

3.3.2.1 *Discussion*—Q defines the bandwidth (or sharpness) of the resonance curve of field intensity plotted against frequency. Q is the reciprocal of the electrical loss with a high Q indicating low electrical losses of the cavity and dielectrics and is obtained by optimum choice of cavity dimensions, use of high conductivity metals (such as silver and copper) with highly polished surfaces (that is, surface roughness much smaller than electrical skin depth at the test frequency). High Q is enhanced by choice of large cavity volume to surface area. Surface irregularities or variations in flatness, radius of curvature, or parallelism of walls, leads to spurious resonance modes which introduce electrical losses and lower the cavity Q.

3.3.3 *microwave, adj*—referring to electromagnetic wavelengths of 30 cm or less where the corresponding frequency is 1 GHz or higher.

3.3.4 *resonant cavity, n*—an enclosure with conducting walls which will support electromagnetic resonance of various specific modes dependent on the cavity geometry and dimensions, and on the integral number of half waves and their directions of propagation as terminated by the cavity walls.

3.3.4.1 *Discussion*—In practice, allowance must be made for input and output coupling holes, probes, or loops. Openings or means of disassembling must be provided for introducing dielectric specimens.

4. Significance and Use

4.1 Design calculations for such components as transmission lines, antennas, radomes, resonators, phase shifters, etc., require knowledge of values of complex permittivity at operating frequencies. The related microwave measurements substitute distributed field techniques for low-frequency lumped-circuit impedance techniques.

4.2 Further information on the significance of permittivity is contained in Test Methods D150.

4.3 These test methods are useful for specification acceptance, service evaluation, manufacturing control, and research and development of ceramics, glasses, and organic dielectric materials.

TEST METHOD A—SHORTED TRANSMISSION LINE METHOD

5. Scope

5.1 This test method covers the determination of microwave dielectric properties of nonmagnetic isotropic solid dielectric materials in a shorted transmission line method. This test method is useful over a wide range of values of permittivity and loss (**1**).[3] It is suitable for use at any frequency where suitable transmission lines and measuring equipment are available. Transmission lines capable of withstanding temperatures up to 1650 °C in an oxidizing atmosphere can be used to hold the specimen.

6. Summary of Test Method

6.1 For an isotropic dielectric medium, one of Maxwell's curl equations is written:

$$\text{curl } H = j\omega\kappa^*\varepsilon_0 E \quad (1)$$

assuming exp *(jωt)* time dependence, where:

κ^* = relative complex permittivity,
ε_0 = (absolute) permittivity of free space, and
ω = $2\pi f$, f being the frequency.

The notation used will be as follows:

$$\kappa^* = \kappa' - j\kappa'' = \kappa'(1 - j \tan \delta) \quad (2)$$

where:

$\tan \delta$ = κ''/κ',
κ' = real part, and
κ'' = imaginary part.

The value of κ^* is obtainable from observations that evaluate the attenuation and wavelength of electromagnetic wave propagation in the medium.

6.2 The permittivity of the medium in a transmission line affects the wave propagation in that line. Obtain the dielectric properties of a specimen by using a suitable line as a dielectric specimen holder. The electromagnetic field traveling in one direction in a uniform line varies with time, t, and with distance along the line, χ, as exp $(j\omega t \pm \gamma\chi)$ where γ is the propagation constant. Assuming that the metal walls of the line have infinite conductivity the propagation constant γ of any uniform line in a certain mode is:

$$\gamma = 2\pi(\lambda_c^{-2} - \kappa^* \lambda^{-2})^{1/2} \quad (3)$$

where:

λ_c = cut-off wavelength for the cross section and the mode in question,
$\lambda (= c/f)$ = wavelength of the radiation in free space, and
κ^* = relative complex permittivity of the nonmagnetic medium.

Since κ^* is complex, γ is complex, that is:

$$\lambda = \alpha + j\beta \quad (4)$$

The field dependence on distance is therefore of the form $e^{-\alpha\chi} e^{-j\beta\chi}$. The wave attenuation is α in nepers per unit length; β is the phase constant, $\beta = 2\pi/\lambda_g$ where λ_g is the guide wavelength in the line. The method of observing α and β by impedance measurements and of representing the behavior of a line containing a dielectric by means of the formalism of transmission line impedance will be outlined briefly (**1**).

6.3 *Impedance Representation of Ideal Problem*—The impedance representation of the ideal problem is illustrated by Fig. 1 for a uniform line terminated by a short. In Fig. 2 a dielectric specimen of length d_s is supposed to fill completely the cross section of the line and be in intimate contact with the flat terminating short. The impedance of a dielectric filled line terminated by a short (**1**), observed at a distance d_s from the

[3] The boldface numbers in parentheses refer to the list of references appended to these test methods.

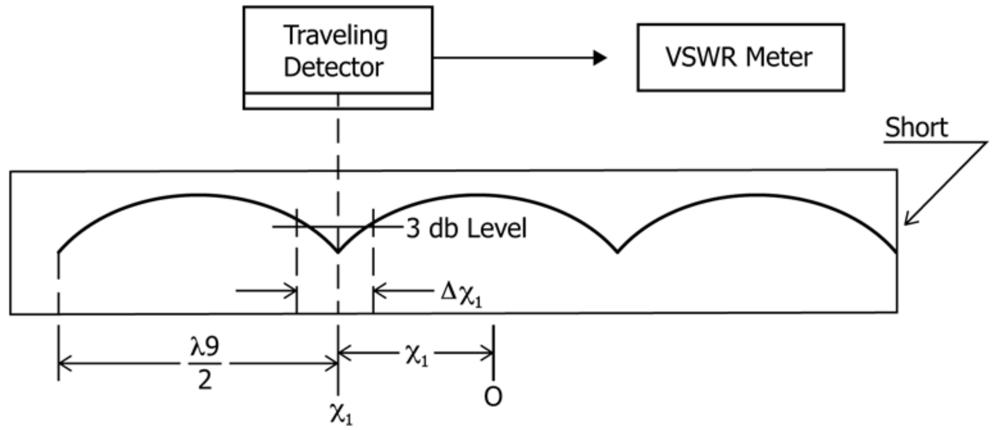

FIG. 1 Standing Wave Established Within Empty Shorted Waveguide

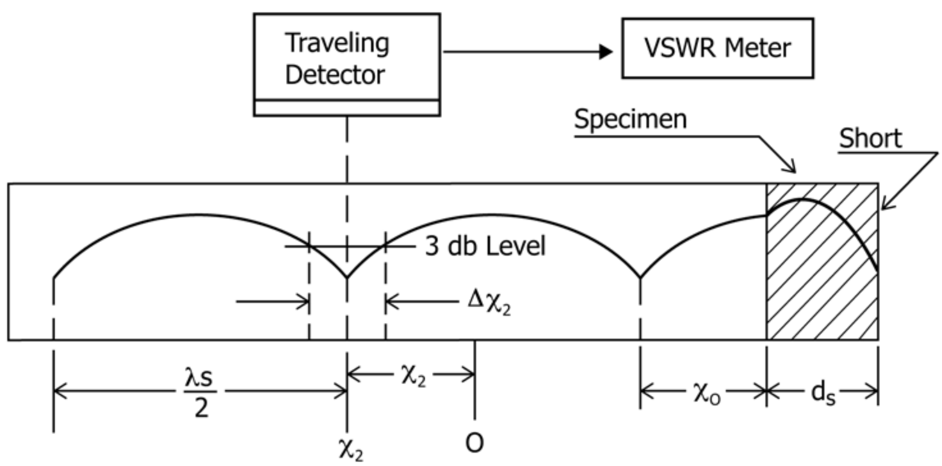

FIG. 2 Standing Wave Established Within Shorted Waveguide After Insertion of Specimen

short (at what is defined as the input face of the specimen) is:

$$Z_{in} = (j\ \omega\ \mu_0 / \gamma_2\ \tanh\ (\gamma_2\ d_s)) \tag{5}$$

where:

μ_0 = the permeability of free space and of the material, and
γ_2 = given by Eq 2, using the dimensions of the line around the specimen.

6.4 *Impedance Measurement:*

6.4.1 The object of the measurement is to obtain the impedance at the input face of the specimen for evaluation of the unknown γ_2 in Eq 4 which in turn allows K^* to be evaluated in Eq 2. The impedance in question is measured by a traveling probe in a slotted section of the line. As illustrated schematically in Figs. 1 and 2, the position of an electric node, that is, an interference minimum of the standing wave, is observed, and also the "width," $\Delta\chi$, of this node is observed. $\Delta\chi$ is the distance between two probe positions on either side of the node position where the power meter indicates twice the power existing at the node minimum. The voltage standing wave ratio denoted by r (r = VSWR) is obtained from $\Delta\chi$ by the equation (see λ_{gs}, Section 11):

$$r = \lambda/\pi\Delta\chi \tag{6}$$

NOTE 3—Refer to Appendix X2 and Appendix X3 for additional comments on errors and refinements in the method to improve accuracy. Also refer to Refs (**1-4**) for information on air gap corrections and use of standard materials to reduce errors and improve accuracy.

When r is small, a correction is necessary (**5**). The load impedance at a phase distance u away from an observed electric node having VSWR = r is:

$$Z_{meas} = Z_{01}(1 - j\ r\ \tan u)/(r - j\ \tan\ u) \tag{7}$$

where:

Z_{01} = $j\omega\mu_0/\gamma_1 = f\mu_0\lambda_g$, assuming the line is uniform and lossless.

6.4.2 It remains to determine r and u correctly, taking into account losses of the line and nonuniformity due to temperature differences, then to equate Z_{meas} and Z_{in} from Eq 6 and Eq 4, and finally to lay out a convenient calculation scheme for κ^*. The measuring procedure for obtaining r and u is discussed in Section 10.

7. Significance and Use

7.1 This test method is useful for quality control and acceptance tests of dielectric materials intended for application at room and substantially higher temperatures. Dielectric measurement capabilities over wide ranges of temperature and over wide, continuous ranges of frequency provide significant usefulness of this method for research and development work.